Ocean Model Development for COAMPS

Paul Martin
Naval Research Laboratory
Stennis Space Center, MS 39529
phone: (228) 688-5447 fax: (228) 688-4759 email: martin@nrlssc.navy.mil

Award #: N0001401WX20609

LONG-TERM GOALS

Develop a coupled ocean-atmosphere prediction system that can be used for hindcasting and forecasting coastal and mesoscale environments. This system is referred to as the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). The atmospheric component of this system was developed by the Atmospheric Dynamics and Prediction Branch of the Naval Research Laboratory (NRL) and is currently in use at NRL and at the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) (Hodur, 1997).

OBJECTIVES

The objectives of this project are to (a) develop an ocean model that contains some of the best features of existing coastal ocean models, meets the Navy's needs for conducting simulations and predictions in littoral and mesoscale environments, and is scaleable on multi-processor computers in common use by the Navy, (b) validate the performance of the ocean model, and (c) fully couple the ocean model with the atmospheric model within the current COAMPS program architecture.

APPROACH

COAMPS consists of coupled ocean and atmospheric models. The ocean model needs to be able to accommodate the wide range of environments and processes that will be encountered in operational use, including complex coastlines and bathymetry, wind and density-driven currents, tides and storm surge, river outflows and coastal runoff, and flooding and drying. The purpose of this project is to develop an ocean model to provide these capabilities. The ocean model being developed in this project is referred to as the Navy Coastal Ocean Model (NCOM).

Based on results from the Coastal Model Comparison study conducted by the NOMP Ocean Model Performance and Evaluation Project at NRL (Martin, et al., 1998), it was proposed that the ocean model to be developed for COAMPS consist of the following main elements: (a) the basic physics and numerics of the widely used Princeton Ocean Model (POM), (b) the combined sigma/z-level vertical grid system used in NRL's Sigma/Z-level Model (SZM), (c) a program structure fully consistent with COAMPS, and (d) some additional capabilities and refinements.

A combined sigma/z-level grid system provides some additional flexibility over a sigma coordinate or a z-level system in setting up a vertical grid for a particular region. With the combined grid /ystem, sigma coordinates are used down to a user-specified depth, and z-level coordinates are used below. The z-level grid, which is generally more robust in regions of steep bottom slopes than sigma

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Ocean Model Development for COAMPS**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,,Stennis Space Center,,MS, 39529**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Develop a coupled ocean-atmosphere prediction system that can be used for hindcasting and forecasting coastal and mesoscale environments. This system is referred to as the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). The atmospheric component of this system was developed by the Atmospheric Dynamics and Prediction Branch of the Naval Research Laboratory (NRL) and is currently in use at NRL and at the Navy’s Fleet Numerical Meteorology and Oceanography Center (FNMOC) (Hodur, 1997).

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

coordinates, can be applied at the depths below which steep bathymetry may cause difficulty with sigma coordinates. The combined grid system also allows comparisons to be made between sigma and z-level coordinates for a particular domain to identify problems that may be occurring with either coordinate system.

COAMPS has a very specific code architecture that is mainly defined by two attributes: (1) model variables are passed via subroutine argument lists rather than by common blocks and (2) model array space is dynamically allocated at run time. The reason for these attributes is to allow the same model code to calculate different nested grids for both the atmospheric and ocean models within a single program, and to avoid having to recompile the program for different simulations with different grids. To utilize the full capability for which COAMPS was designed, an ocean model being developed for use in COAMPS needs to be structured to be consistent with the COAMPS code architecture. Most existing ocean model codes are not structured in this way.

It was desired to include some additional capabilities in NCOM that are not currently available in POM. These include an explicit source term to simplify inclusion of river and runoff inflows, options for forcing by the local tidal potential and the surface atmospheric pressure gradient, and the choice of either the Mellor-Yamada Level 2.5 turbulence closure scheme as used in POM or the simpler and more efficient Mellor-Yamada Level 2 scheme.

Because of the increasing use of multi-processor computers by Navy operational and research centers, NCOM is being made to be scalable on commonly used multi-processor computers. Alan Wallcraft of NRL, who has significant experience with scalable model design, is assisting in this effort. Alan's work on NCOM is funded by the Common High Performance Computing Software Support Initiative (CHSSI).

NCOM is being validated by testing its ability to correctly simulate basic physical processes and by comparing model simulations in some real environments with observations. Coupling between NCOM and the COAMPS atmospheric model is being tested in the Mediterranean.

The coupling of NCOM with COAMPS is very much a joint effort with NRL Monterey, and several personnel from the atmospheric modeling group at NRL Monterey are involved in this effort including Richard Hodur, Xiaodong Hong, Julie Pullen, Jim Cummings, Sue Chen, and Jim Doyle. The NRL Monterey effort is funded separately and is being reported separately. This report will focus mainly on the work done at NRL Stennis, but some of the tasks reported here involve joint work.

WORK COMPLETED

A Fortran code for NCOM has been developed that is fully consistent with the COAMPS code architecture, i.e., that includes dynamic allocation of array space, passes all model variables through subroutine argument lists, and provides for an arbitrary number of levels of grid nesting. The model contains options for Smagorinsky or grid-cell Reynolds number horizontal mixing, Mellor-Yamada Level 2 or 2.5 vertical mixing, and 3^{rd}-order, upwind advection. The NCOM code is fully scaleable, except for feedback from the nested grids to the main grid, runs on the SGI Origin 2000, Cray T3E, IBM SP, and Sun E10000, and provides a choice of MPI, SHMEM, and OpenMP for communication between processors. A basic description of NCOM is provided in Martin (2000). A user's guide for NCOM is available and has been updated to include recent changes to the model.

In FY01, a flux coupler was developed to access surface flux fields output by the COAMPS atmospheric model and interpolate them in space and time to the ocean model grid. The surface flux fields include the surface atmospheric pressure, surface wind stress, solar radiation, surface heat flux (net longwave radiation and latent and sensible heat flux), and precipitation and evaporation. The procedure used to interpolate the fields spatially is to mask out the values over the land points of the atmospheric model grid and then extend the values at the sea points out over the land points prior to interpolation to the ocean model grid. With this procedure, only values of the atmospheric surface flux fields at sea points are used to force the ocean model. This is necessary because of the large land-sea gradients that can occur in the surface flux fields. Bicubic polynomial interpolation is used for the wind stresses to maintain smooth gradients and bilinear interpolation is used for the other fluxes.

An automated procedure was set up to put river inflows in an arbitrary ocean model domain. The basis of the procedure is the global river database of Perry, Duffy, and Miller (1996) (obtained from Julie McClean, personal communication). This database contains the annual mean discharge rates for 981 rivers and the latitude and longitude location of the river mouth. The location of the river mouth is of key importance, as many river databases quote discharge rates upstream of the mouth and don't provide the location of the mouth itself. The river database was reformatted to allow prescription of monthly mean discharges and temperatures. In the absence of actual river temperature data, the monthly discharge temperatures have been set from ocean temperature climatology at the location of the river mouth. The monthly discharge values currently just contain the annual mean; however, the seasonal variation of the river discharge rates will be derived from other river databases that are available. A routine was written to insert the rivers into an arbitrary domain at the nearest coastal grid point to the river mouth.

The Mediterranean is being used as the focus area for testing the COAMPS coupled ocean-atmosphere modeling system. For this work, NCOM has been set up for the Mediterranean domain on several grids of differing horizontal resolution. The main grid of interest for the coupling work is a 6-km grid, but 9- and 20-km grids are also being used to provide more rapid turn around for basic testing. NCOM is being run with both climatological atmospheric fluxes and with real-time fluxes from the COAMPS atmospheric model. The COAMPS atmospheric model is being run on a standard, Navy operational grid of 27-km resolution that encompasses the Mediterranean Sea and surrounding countries.

Spinup runs were conducted on both the 6- and 9-km Mediterranean grids using hourly COAMPS atmospheric fluxes for the period October 1, 1998 to October 1, 1999 and river inflows from a number of rivers.

RESULTS

The seasonal circulation in the Mediterranean has been simulated previously with NCOM using climatological atmospheric forcing on a 9-km grid. NCOM was able to reproduce many of the known circulation features in the Mediterranean including the Algerian, Ionian, and Asia Minor currents and the Alboran, Cretan, Ierapetra, Rhodes, Latakia, Antalya, and Peloponnesian gyres. Transports calculated through a number of passages including the Corsica Passage, the Straits of Sicily, and the Straits of Otranto were in fairly good agreement with observed transports.

The flux coupler has been carefully tested on both single and multi-processor computers. The use of atmospheric fluxes from only the sea points on the atmospheric grid avoids spurious gradients in the fluxes that can occur near coastlines if the large gradients in the atmospheric fluxes at land-sea boundaries are not accounted for.

However, a problem that remains when using atmospheric heat fluxes without feedback of the ocean model sea-surface temperature (SST) to the atmospheric model is that the fluxes can become seriously in error when the ocean model SST changes significantly from the SST used for the atmospheric model run. (This, of course, is the main reason for developing atmosphere-ocean coupling.) The most noticeable example of this in the Mediterranean simulations is a spuriously large drop in the ocean SST during cold-air outbreaks in the shallow bays of the eastern Adriatic, but the problem occurs to a lesser degree in other areas as well. A common fix that is employed for this problem is to calculate surface fluxes with bulk formulas using the model SST and basic atmospheric parameters (air temperature, humidity, etc.) from the atmospheric model. The flux coupler will be modified to provide this option. This procedure has its shortcomings as well (e.g., the ocean model SST tends to be driven towards the SST used when the atmospheric model was run), but the errors tend to be less severe than those resulting from the use of the heat fluxes calculated by the atmospheric model when there is no feedback to the flux calculation from the predicted SST.

Another problem observed in the ocean model simulations was occasional horizontal grid-scale noise in the near-surface temperature field. The main cause appeared to be vertical mixing (as discussed in Martin et al. 1998). This noise was significantly reduced by using 3rd-order upwind advection instead of 2nd order and by using Mellor-Yamada Level 2.5 mixing instead of Level 2.

The automated river-input procedure was tested in the Mediterranean domains, which resulted in the insertion of 54 rivers. No problems were observed in integrating the Mediterranean domains for several years with the river inflows. Note that this automated river input procedure is most appropriate for large domains with coarse horizontal resolution and/or small rivers. For high-resolution domains, the details of the river mouth and river input may need to be more carefully prescribed.

The Mediterranean spinup runs with hourly COAMPS atmospheric fluxes show much more variability than the runs with climatological fluxes. The real-time fluxes generate more intense mixing events. The surface salinity shows the river plumes responding to changes in the winds on time scales of a few days. Further refinement and analysis of the spinup runs is planned.

IMPACT/APPLICATIONS

The ocean and the atmosphere are strongly coupled in coastal regions, and a combined ocean-atmosphere modeling system is frequently the optimal means of hindcasting and forecasting coastal areas. COAMPS is being developed by NRL to provide a high-resolution, coupled ocean-atmosphere prediction capability.

The payoff from this ocean model development project will be a functional and flexible model for ocean prediction that can be run by itself or can be run fully integrated with an atmospheric model within the COAMPS framework.

TRANSITIONS

As part of the COAMPS system, NCOM's transition route into operations is through 6.4 SPAWAR funding for COAMPS. If NCOM is transitioned through this path, it will be run operationally at the forecast centers as part of COAMPS.

Within the NOMP COAMPS project, NCOM is currently being applied to the Mediterranean for testing with fields from the COAMPS atmospheric model, and current plans are to extend the coupled testing to other domains. This work is being done jointly by NRL Stennis and NRL Monterey.

NCOM is being used in the NOMP 6.2 Coastal and Semi-Enclosed Seas Project at NRL for simulations of the East Asian Seas. These simulations will use data assimilation and real-time atmospheric forcing to model the evolution of the northwest Pacific in real time.

A global version of NCOM has been transitioned to the 6.4 SPAWAR Global Modeling Project at NRL. This model uses a curvilinear grid to cover the entire global ocean including the arctic.

NCOM is being used by NRL's CoBALT (Coupled Bio-physical-dynamics Across the Littoral Transition) Project to simulate the ocean off the U.S. west coast.

RELATED PROJECTS

NRL-Monterey is being funded by NOMP to assist in the development of NCOM and the installation of NCOM into COAMPS.

A joint project between NRL-Stennis and NRL-Monterey, entitled "Ocean Data Assimilation for COAMPS", is developing an ocean data assimilation system for COAMPS.

Dr. Alan Wallcraft of NRL, working under the CHSSI Program, has been helping to parallelize the NCOM code.

REFERENCES

Hodur, R. 1997: The Naval Research Laboratory Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Mon. Wea. Rev.*, *125*, 1414-1430.

Martin, P. J., G. Peggion, and K. J. Yip, 1998: A Comparison of Several Coastal Ocean Models. NRL Report NRL/FR/7322-97-9672, Naval Research Laboratory, Stennis Space Center, MS 39529, 96 pp.

Martin, P. J., 2000: A Description of the Navy Coastal Ocean Model, Version 1.0. NRL Report NRL/FR/7322-00-9962, Naval Research Laboratory, Stennis Space Center, MS 39529, 40 pp (in press).

Perry, G.D., P.B. Duffy, and N.L. Miller, 1996: An Extended Data Set of River Discharges for validation of the Hydrological Cycle within GCMs. *J. Geophysical Res.*, *101*, *D16*, 21339-21349.

PUBLICATIONS

Martin, P. J., 2000: Description of the Navy Coastal Ocean Model Version 1.0. NRL Report NRL/FR/7322-00-9962. Naval Research Laboratory, Stennis Space Center, MS. 42 pp.

Rochford, P. A., and P. J. Martin, 2001: Boundary Conditions in the Navy Coastal Ocean Model. NRL Report NRL/FR/7330-01-9992. Naval Research Laboratory, Stennis Space Center, MS. 31 pp.